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THE RELATIVE SAFETY OF BRASS, COPPER, AND STEEL GAUZES IN MINERS' FLAME SAFETY-LAMPS

BY

L. C. ILSLEY and A. B. HOOKER

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

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First edition April, 1921.

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FIGURE 1. Koehler lamp, model No. 1 5

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RELATIVE SAFETY OF BRASS, COPPER, AND STEEL GAUZES IN MINERS' FLAME SAFETY LAMPS.

By L. C. Ilsley and A. B. Hooker.

INTRODUCTION.

Flame safety lamps have been used for about 100 years in coal mines where explosive mine gas (methane) might accumulate and thus render dangerous the use of ordinary unprotected flame lamps. Flame safety lamps are used not only for illumination but also for detecting the presence of dangerous proportions of methane mixed in the air of the mine.

A typical flame safety lamp in general use in gaseous mines in the United States is shown in figure 1, page 5. This figure also shows a section of the inner and outer wire gauzes. The safety of the lamp depends chiefly upon the cooling qualities of these gauzes. If a miner enters a part of the mine where there is methane in the air, the methane enters the lamp, and coming in contact with a wick flame is ignited and continues to burn within the gauze without igniting the methane surrounding the lamp. If the air within the mine is traveling at a velocity of several hundred feet per minute the burning gases may be driven through the gauze by the air current. If the gauzes are properly designed and of the proper material, these burning gases will be so cooled as they pass through the gauze that they will not cause an ignition of the gas surrounding the lamp. In order to test the effectiveness of a given safety lamp, tests have been made in moving explosive mixtures of gas and air arranged to simulate conditions in mines.

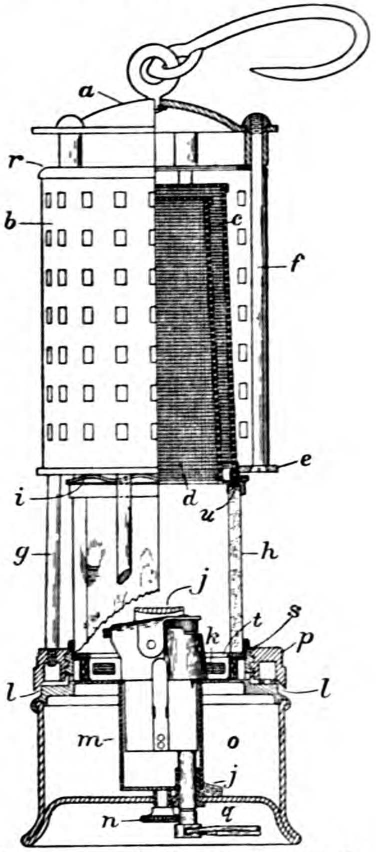

FIGURE 1.—Koehler lamp-model No. 1.—*a*, Steel hood; *b*, steel bonnet; *c*, outer steel gauze; *d*, inner steel gauze; *e*, iron ring for standards (5); *f*, stay screws; *g*, brass standards (5); *h*, glass globe; *i*, spring steel expansion-ring; *j*, wick; *k*, inlet ring; *l*, air inlet; *m*, igniter; *n*, wick adjuster; *o*, steel fuel-fount; *p*, lower ring; *q*, igniter pull-bar; *r*, ring for stiffening bonnet; *s*, rubber-band gasket; *t*, flexible fiber gasket; *u*, asbestos gasket.

The Bureau of Mines has investigated many features relating to the safety of flame lamps, and in 1915 it officially established schedule 7, whereby flame lamps having prescribed qualifications would be approved by the bureau as permissible for use in gaseous mines. Among the regulations are the following requirements for the gauzes of flame safety lamps:

> The lamp must be provided with double gauzes or with some other adequate arrangement serving the same purpose. Every gauze must be of steel or best charcoal annealed iron wire of not larger than 27 Brown and Sharpe gage (0.014 inch in diameter), with 28 meshes to the linear inch (784 to the square inch), nor less than 29 Brown and Sharpe gage (0.0125 inch in diameter), with 29 meshes to the linear inch (841 to the square inch).

Frequently the use of brass or copper as a gauze fabric for a flame lamp was advocated, and one company, thinking that the kind of material had no bearing on safety, substituted brass for steel in lamps stamped with the bureau's approval, without notifying the bureau of the change.

The specifications relative to material and construction of gauzes were in the main based on European practice and investigations.

The purpose of the investigation described in this paper was to conduct a limited number of check tests in order to determine to what extent European results should apply to American types of flame lamps, and consequently whether or not the specifications of schedule 7 for gauzes required revision.

SCOPE OF THE INVESTIGATION.

The investigation in the main was conducted along the following lines:

1. A study of European reports on similar research.
2. A selection of critical tests having a bearing on safety.
3. The obtaining of enough material to duplicate such tests.
4. The performance of check tests in accordance with these selections.
5. A report and analysis of the results.

ACKNOWLEDGMENTS.

The authors wish to acknowledge assistance by the Koehler Manufacturing Co. (Inc.), of Marlboro, Mass., in supplying special gauze for the investigation. Acknowledgment is due the chemical and nonferrous metals sections of the Pittsburgh station of the Bureau of Mines for assistance in the analysis of materials and in the preparation of photomicrographs. Acknowledgment is also made to J. W. Paul, coal-mining engineer of the bureau, for advice and criticisms. The work done by European

investigators, especially that of Messrs. Watteyne and Stassart,[1] has been closely studied and has had a bearing on the course of the investigation. E. J. Gleim, assistant electrical engineer, and R. A. Kearns, jr., electrical engineer of the bureau, assisted with the tests.

MATERIAL TESTED.

The material tested consisted of the following staple gauzes: Steel and brass gauzes designed for Koehler lamp, steel gauzes for Davy lamp, and steel gauzes for Clanny lamp. Also the following gauzes ordered especially for this investigation: Koehler copper gauzes, Clanny brass gauzes, Clanny copper gauzes. The Koehler gauzes were used in both the Koehler and Seippel lamps.

The following tables give the number, kind, and types of gauzes tested, also the physical characteristics and analyses of the material.

Number, kind, and type of gauzes tested.

Gauze material.	Koehler double gauzes (gauzes used in both Koehler and Seippel lamps).		Clanny (single gauze).	Davy (single gauze).
	Outer.	Inner.		
Steel	10	24	6	3
Brass	22	10	11	None.
Copper	14	12	12	None.

Physical characteristics of gauze material tested.

Gauze material.	Melting point,[a] ° C.	Thermal conductivity,[a] at 0° C.	Specific heat,[b] at 0° C.
Steel	1,375	0.1300	0.1116
Brass	1,000	.234	.0883
Copper	1,065	.720	.0898

[a] Van Nostrand's Chemical Annual, 1918, pp. 11, 425.
[b] Castell-Evans, John, Physico-Chemical Tables, Chemical Engineering and Physical Chemistry, 1902, vol. 1, pp. 183, 184.

Analyses of gauze material tested.

Steel.[a]		Brass.[a]		Copper.[b]	
	Per cent.		Per cent.		Per cent.
Silicon (Si)	0.018	Copper (Cu)	80.09	Copper (Cu)	99.97
Manganese (Mn)	.31	Zinc (Zn)	19.80		
Phosphorus (P)	.014	Iron (Fe)	.03		
Carbon (C)	.15				
Sulphur (S)	.039				

[a] Analyses by W. A. Selvig, Bureau of Mines.
[b] Analysis by J. H. Capps, Bureau of Mines.

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[1] Watteyne, V., and Stassart, S., [Experiments on safety lamps]: Ann. mines de Belgique, t. 9, 1904, pp. 947–1251.

EQUIPMENT AND APPARATUS USED.

The equipment used in the tests comprised the following flame lamps:

One bonneted steel-frame Koehler lamp.
One unbonneted steel-frame Seippel lamp.
One bonneted steel-frame Clanny lamp.
One unbonneted steel-frame Clanny lamp.
One unbonneted steel-frame Davy lamp.

The Koehler lamp (see fig. 1) was a double-gauze bonneted steel lamp. This lamp has a bottom feed, an internal friction relighter, and it burned a good grade of gasoline fuel.

The Seippel lamp was a double-gauze unbonneted steel lamp, and it burned gasoline fuel.

The Clanny bonneted lamp was a middle-feed single-gauze lamp. The fuel used was mineral seal oil.

The Clanny unbonneted lamp was a single-gauze lamp and burned mineral seal oil.

The Davy lamp used was a No. 2 standard Davy lamp of American manufacture, and burned mineral seal oil.

The apparatus used consisted chiefly of a flame-testing gallery shown in figure 2. The gallery proper comprises rectangular passageways through which desired proportions of gas and air, properly mixed, can be passed in various directions. The lamp under test can be placed in an air mixture moving in any of the various directions by means of doors 1, 2, 3, 4, and 5. The direction of the air mixture is governed by gates 1 and 2.

The fan *k* operated by an electric motor supplies the required volume of air. The blower *f* operated by the electric motor *g* assures a good pressure of gas.

The air and gas are measured by means of standard orifices shown at *n* and *o*, sectional views of chambers *h* and *j*. Manometer gages *p* and *q* give the pressure on either side of these orifices, which determines the amount of air and gas flowing through the orifices.

DETAILED TEST PROCEDURE.

SELECTION OF LAMPS.

No attempt was made to conduct an exhaustive investigation that would require a great many lamps, corresponding quantities of gauze, and hundreds of tests on account of the many types of flame lamps and the numerous modifications of types. A study of the data of previous investigations led to the selection of lamps that would be representative of the following general types:

A single-gauze unbonneted lamp, Davy type.

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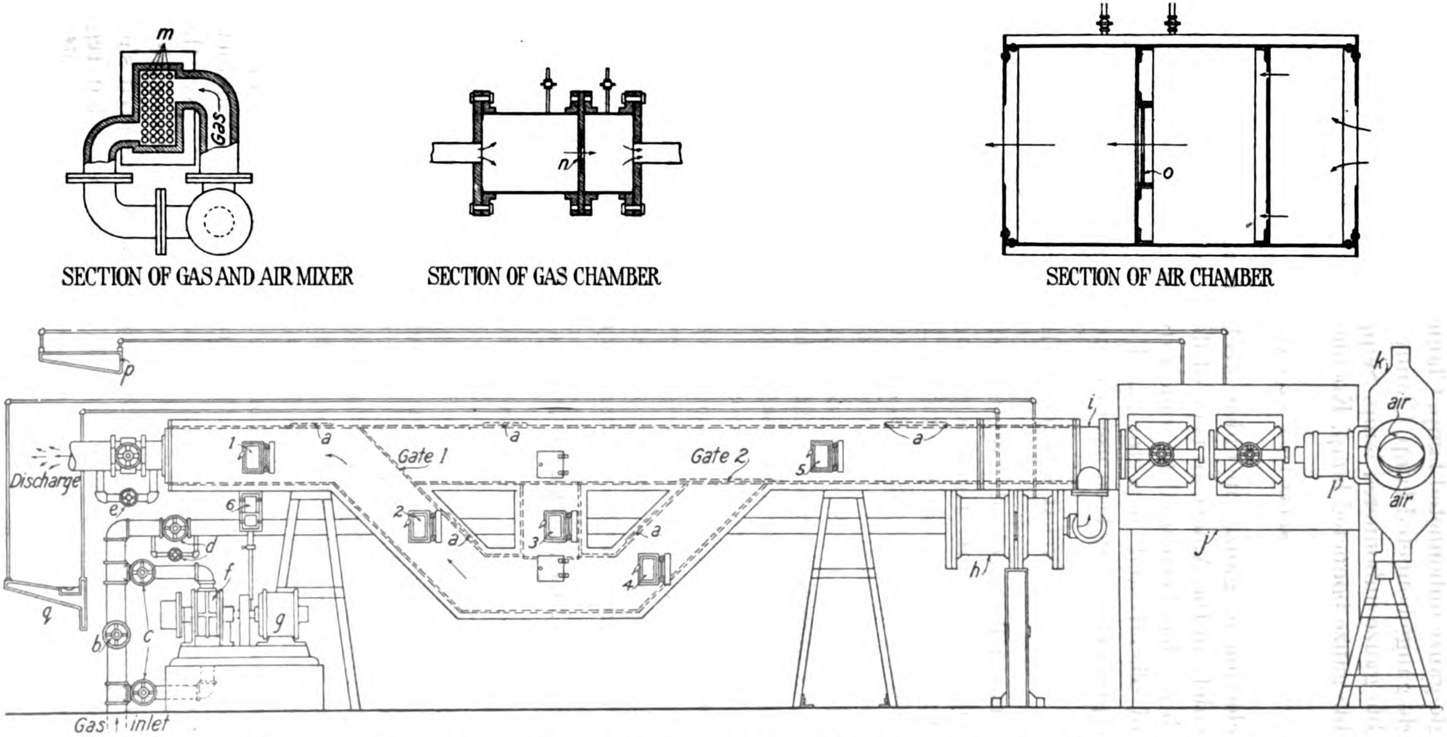

FIGURE 2.—Flame-testing gallery. *a*, Explosion relief door; *b*, main-line gas valve; *c*, booster-line gas valve; *d*, gas-adjusting valves; *e*, air-adjusting valves; *f*, gas pressure booster; *g*, motor for "*f*"; *h*, gas chamber; *i*, gas and air mixer; *j*, air chamber; *k*, centrifugal fan for air supply; *l*, centrifugal-fan motor; *m*, tubular air passages with perforations for admixture of gas; *n*, gas orifice; *o*, air orifice; *p*, air-pressure gage; *q*, gas-pressure gage. Doors 1, 2, 3, 4, 5, and 6 are for inserting lamps and for observation of tests.

A single-gauze unbonneted lamp, Clanny type.
A single-gauge bonneted lamp, Clanny type.
A double-gauze unbonneted lamp, Seippel type.
A double-gauze bonneted lamp, Koehler type.

SELECTION OF GAUZES.

The selection of gauzes included steel, brass, and copper. Steel is used widely in the American type of flame safety-lamps in general service; brass has been used to some extent for lamps designed for the use of officials and inspectors, and copper, because of its nonmagnetic properties, has been used by surveyors.

GENERAL NATURE OF THE TESTS.

The tests chiefly involved subjecting the lamp, equipped with one of the gauzes under investigation, to currents of explosive gas and air moving in a horizontal direction. The tests were made in the testing gallery shown in figure 2, and the lamp was suspended in the path of the air mixture. The lowest probable velocity at which an explosion would result was ascertained for each gauze, for the several types of lamps, and for different percentages of gas in the air mixture. Tests were likewise made using the same gauze in successive trials to determine the effect of oxidation on the safety of a given material. Physical measurements were made to check the stated dimensions of the gauze material used, and measurements were made of some of the gauzes, before and after tests, in order to determine the change in physical condition through oxidation.

PRELIMINARY PREPARATION.

OPERATING DATA.

In conducting tests on any lamp it was first necessary to determine the relative obstruction of the lamp to the passage of the air mixture in order to ascertain the effective cross section of testing gallery at the point where the lamp was suspended. This information was obtained by deducting from the cross-sectional area of the gallery the projected cross section of the lamp for the particular position of the lamp—horizontal, vertical, or at a 45° angle. Several air velocities were then selected at which tests were to be conducted, and determinations were made for the quantity of air to give these velocities. On the basis of the quantity of air necessary to give the required velocities for any given lamp, curves were prepared showing the correct pressure-gage reading on the manometer that registers the drop in pressure across the air and the gas measuring orifices respectively.

PREPARATION OF GAUZES AND LAMPS.

The coating on new steel gauzes, applied to prevent oxidation previous to use, was burned off previous to assembly in the lamp. Gauzes previously used were cleaned with a wire brush unless the effect of the accumulation of oxide was being studied. The lamp was lighted and allowed to burn a sufficient length of time for the parts to become warm and the flame stable.

OPERATION OF THE TESTING GALLERY.

In making tests of this kind the ability to control the conditions of the test properly is of importance in relation to the accuracy of the results obtained and the conclusions drawn. The operation of the flame-testing gallery was under excellent control, and the ability to duplicate tests under any given condition was proved repeatedly.

The first step in the operation after the lamp was put in position was to obtain, by using air only, the approximate velocity desired. By proper selection of orifices and adjustments of valves the gas was quickly added and final adjustment made by obtaining exact manometer setting for both air and gas. The duration of a test was usually five minutes unless the lamp failed sooner. In some tests made to study the effect of oxidation, the tests were continued 10 minutes.

The proper manipulation of the gallery requires two operators—one to adjust valves, obtain pressure settings, and maintain the settings throughout the test; the other to observe the behavior of the lamp from the time gas is added until the test is completed.

The second operator observed, as far as possible, the condition of the wick flame, the burning of the gaseous mixture within the lamp, and all happenings pertinent to the tests. These observations and the reports of the inspection of the lamp and gauze were carefully recorded at the end of each test.

SPECIAL TESTS TO DETERMINE EFFECT OF OXIDATION.

Special tests were made with used gauzes in order to determine, if possible, whether the oxide coating of the gauze, or the reduced cross section of the wire, in those cases where the coating could be brushed off, had an effect on the safety of the gauze.

PHYSICAL MEASUREMENTS.

Specimens of the several samples of gauze were measured for over-all dimensions and for diameter of wire and mesh of gauze.

In order to determine physical changes due to oxidation, certain gauzes were weighed before the test, tested, thoroughly cleaned by a wire brush, and reweighed. The weighing was done with an analytical balance.

PHOTOGRAPHS AND PHOTOMICROGRAPHS.

In order to have permanent record of the appearance of the gauze when oxidized, ruptured, and otherwise distorted, numerous photographs and photomicrographs of typical results were procured. The photomicrographs proved of great help in the interpretation of results.

CHEMICAL ANALYSES OF GAUZE MATERIAL.

An analysis of each of the materials used as gauzes was made in order to identify the material and to relate the results to those of previous investigators.

DISCUSSION OF RESULTS OF TESTS.

Several factors bearing on the safety of flame-lamp gauzes are discussed with respect to their effect on safety in the order given below.

1. Number of gauzes used.
2. Physical dimensions and construction of the gauzes.
3. Physical characteristics of the gauze material used.
4. Velocity of the air mixture.
5. Proportion of gas in the air mixture.
6. Construction of the lamp.

DEFINITION OF TERMS USED.

Rupture.—In this report, physical breakdown of a gauze caused by oxidation or by the melting away of enough material to permit the flame to pass through the resulting openings is termed failure by rupture.

Passage.—The passing of flame through the gauze when no physical breakdown of the gauze takes place is termed failure by passage.

Explosions.—Ignition of the air mixture exterior to the lamp due either to rupture or to passage is recorded as an explosion.

Air mixture.—Air mixture refers to a mixture of Pittsburgh natural gas and air.

Gas.—Refers to Pittsburgh natural gas.

NUMBER OF GAUZES USED.

The safety of a flame lamp equipped with either of the fabrics investigated is dependent on the arrangement of the gauze within the lamp. There are two customary designs, using (1) one gauze and (2) two concentric gauzes. In some designs more than two concentric gauzes have been adopted.

SINGLE-GAUZE LAMPS.

A flame lamp of the single-gauze type may be either bonneted or unbonneted. The gauze consists of a single thickness of fabric, except at the top, where a cap gives a double thickness of fabric.

A single gauze in an unbonneted type of lamp offers the least safety of any type of protection in use. Air mixtures of comparatively low velocity will produce an explosion exterior to the lamp. Any rupture in the fabric means a direct path for the flame to pass into the surrounding atmosphere. In bonneted lamps the gauze is shielded from high-velocity air mixtures and the lamps, therefore, are much safer.

DOUBLE-GAUZE LAMPS.

A flame lamp with double gauze has two concentric gauzes; each layer is made up of a single fabric without the cap, but the outer gauze is proportioned larger throughout to insure an air space at all points between it and the inner gauze.

A multiple-gauze lamp is undoubtedly safer than a single-gauze type, but not in proportion to the number of gauzes used. In unbonneted lamps it requires only slightly higher velocities of air mixture to produce failures as compared with single-gauze lamps. The double-gauze bonneted lamp is very safe, having not only the advantage of the bonnet in protecting the gauzes from high velocities, but having also an extra gauze as a provision against accident.

NATURE OF THE TESTS.

The three gauze fabrics were each tested in both single and double gauze lamps of the bonneted and unbonneted types. In these tests the lamps equipped with a certain gauze were subjected to air mixtures of varied percentages of gas and air, moving at varied horizontal velocities. The duration of each test was usually five minutes unless failure occurred in less time.

The following table shows the comparative safety of the different fabrics when tested in single and in double gauze unbonneted lamps:

Comparative safety of single and double gauzes in unbonneted lamps.

Gauze material.	Gas.	Velocity at which explosion occurs.	
		Single gauze.	Double gauze.
	Per cent.	*Feet per minute.*	*Feet per minute.*
Steel	11	1,000	1,500
Do	8.6	1,200	1,500
Do	7	1,200	1,200
Do	6	1,200	1,200
Brass	11	600	700
Do	8.6	800	1,000
Do	7	1,000	1,200
Do	6	1,000	1,200
Copper	11	[a] 600–700	1,000
Do	8.6	800–1,000	1,200
Do	7	1,000	1,500
Do	6	1,000	1,500–2,000

[a] Estimated.

A similar table of results for single and double gauzes in bonneted lamps is not given, as no explosions occurred in the tests of bonneted lamps. The tests with unbonneted lamps indicated that safety for all materials increased when double gauzes were used. This increase of safety is more marked for copper than for brass or steel gauzes. At 6 and 7 per cent of gas, steel gauzes showed no increase of safety for double-gauze construction.

PHYSICAL DIMENSIONS AND CONSTRUCTION OF GAUZES TESTED.

Although the safety of gauzes of any material is dependent upon the physical dimensions of the material, that factor was not considered in this investigation. The material selected was so far within conservative specifications as to mesh, size of wire, and over-all dimensions as to need no special comment. An exhaustive investigation might be conducted using such factors as variables, and much might be learned from such an investigation; the chief aim of the present investigation, however, was to study the relative safety of the materials—steel, brass, and copper—when fabricated in a conservative manner.

In order to obtain a record of the physical dimensions of the material tested, specimens of each material were measured for over-all dimensions, and for wire and mesh dimensions.

OVER-ALL DIMENSIONS.

By over-all dimensions is meant the height of the gauzes or gauze and their diameter at top and bottom. The over-all dimensions of the gauzes tested are given in the following:

Over-all dimensions of gauzes tested.

Type of lamp.	Gauze material.	Diameter of gauzes.		Height of gauzes.
		Bottom.	Top.	
		Inches.	*Inches.*	*Inches.*
Koehler (outer gauze)	Steel Brass Copper	2.12	1.94	4.06
Koehler (inner gauze)	Steel Brass Copper	1.66	1.37	3.67
Clanny	Steel Brass Copper	1.94	1.53	3.75
Davy	Steel	1.53	1.53	4.75

WIRE AND MESH DIMENSIONS.

By wire dimensions is meant the diameter of the wire making up the fabric. The wire specifications in Schedule 7 [2] undoubtedly apply

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[2] Procedure for establishing a list of permissible miners' safety lamps: Schedule 7, Bureau of Mines, Jan. 30, 1915.

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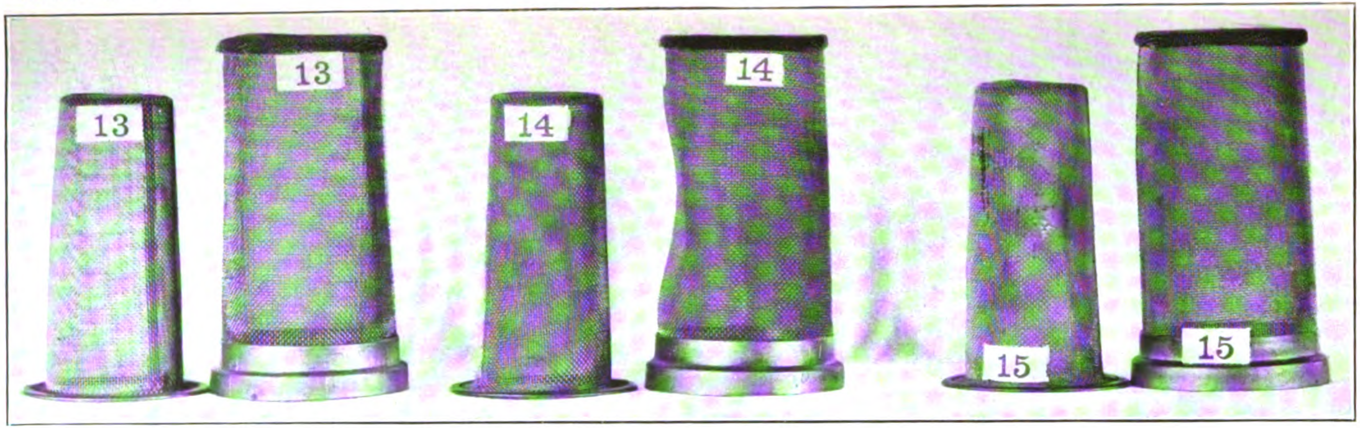
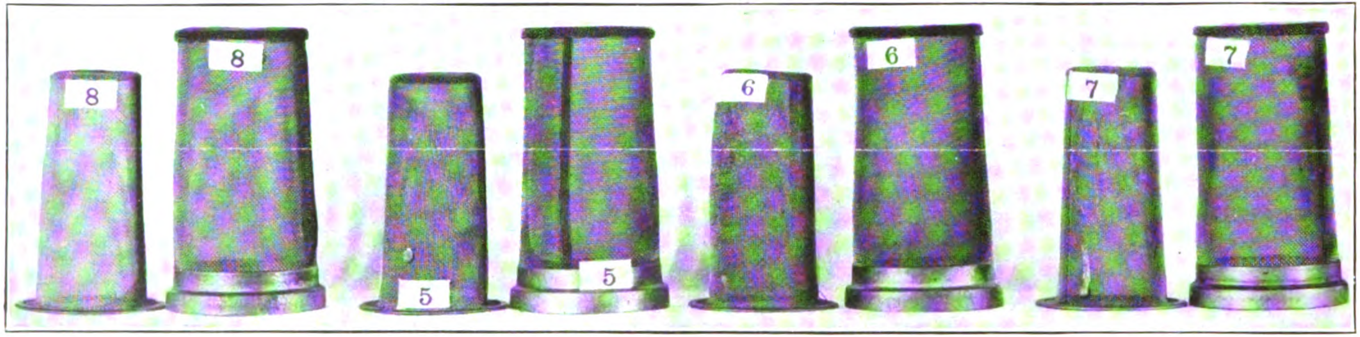


A. GAUZES TESTED IN UNBONNETED SEIPPEL LAMP, SHOWING APPEARANCE OF FABRICS AFTER FAILURE IN 6 PER CENT GAS.



B. GAUZES TESTED IN UNBONNETED SEIPPEL LAMP, SHOWING APPEARANCE OF FABRICS AFTER FAILURE IN 7 PER CENT GAS

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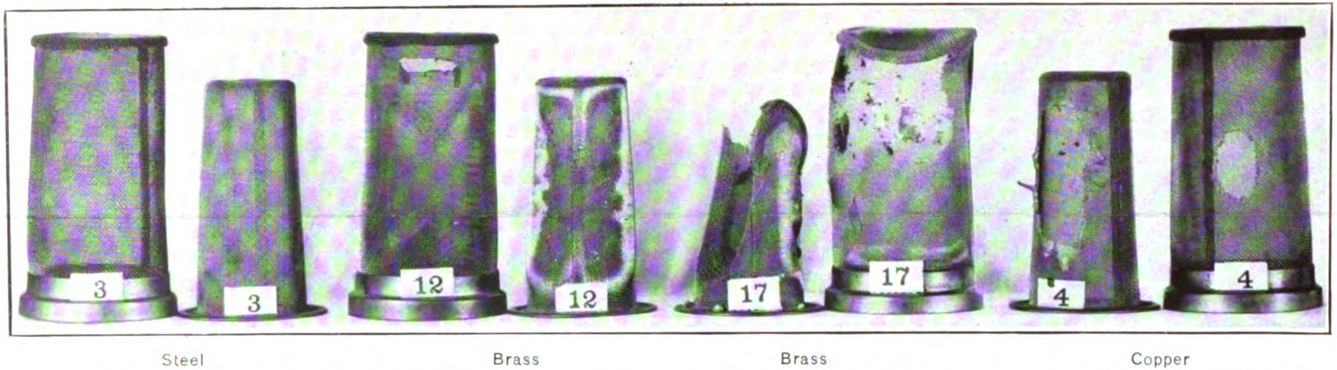
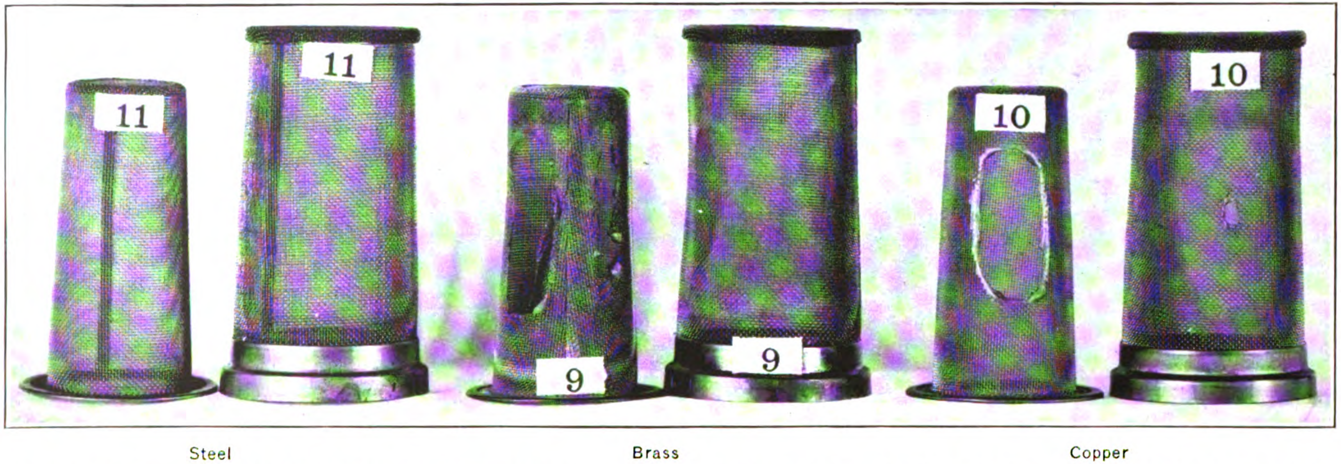


A. GAUZES TESTED IN UNBONNETED SEIPPEL LAMP, SHOWING APPEARANCE OF FABRICS AFTER FAILURE IN 8.6 PER CENT GAS.



B. GAUZES TESTED IN UNBONNETED SEIPPEL LAMP, SHOWING APPEARANCE OF FABRICS AFTER FAILURE IN 11 PER CENT GAS.

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to wire previous to fabrication. Such specifications should be limited by tolerances, having reference to the commercial difficulties in wire drawing and the possible stretching of the wires during weaving. By mesh is meant the number of warp and woof wires per linear inch. The specifications for gauzes usually call for square mesh; that is, for an equal number of warp and woof wires. Such specifications should also indicate whether tolerance will be allowed.

Samples of each of the materials were measured for wire dimensions by means of a Leitz microscope, and mesh dimensions were determined by flattening a piece of the gauze and counting the warp and woof wires per linear inch. The results obtained are given in the following table:

Wire and mesh dimensions of gauzes tested.

Type of lamp.		Wire diameter.	Meshes.
		Inches.	*Per linear inch.*
Koehler	steel	0.0125	28
	brass	.0128	28
	copper	.0136	[1] 29
Clanny	steel	.0144	28
	brass	.0144	28
	copper	.0145	28
Davy, steel		.0137	28

[1] These gauzes were not square mesh, but had 30-warp and 28-woof wires per inch, or the equivalent of a 29-mesh gauze.

PHYSICAL CHARACTERISTICS OF THE GAUZE MATERIAL.

The relative safety in the use of gauze depends on the following physical characteristics of the material:

(1) Melting point; (2) relative conductivity of heat; (3) specific heat; (4) oxidation.

MELTING POINT.

The melting points for the materials used—steel, brass, and copper—are given as 1375°, 1000°, and 1068° C.[3] The melting point of a material probably has more influence on the safety of that material for use as a gauze than any other physical characteristic. A large proportion of the failures obtained in the present investigation resulted from a fusion of the material.

No tests were made to study especially the effect of the melting point, yet numerous tests in which failure occurred gave interesting data on the behavior of brass and copper when near their fusion temperature. Samples of such tests have been selected for discussion.

Plates I and II are photographs of double gauzes that have been tested in double-gauze unbonneted lamps at 6, 7, 8.6, and 11 per cent gas, respectively.

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[3] Van Nostrand's Chemical Annual, 1918, pp. 11, 425.

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The manner in which brass gauzes fuse when heated to their melting point is shown in the inner gauze of set 9, Plate II, *B*. The metal around the edge of the hole fused and ran down the fabric, lodging at points where the surface of the gauze was uneven. The fused metal was in a plastic state, and in some of the tests was carried, probably by the force of the explosion, to the opposite side of the gauze, where it adhered in the form of globules. Sets 4 and 10 of Plate II show similar tests with copper gauzes. Copper that had been melted is seen all around the holes in these sets, showing the tendency of the copper to fuse to itself in contrast to brass, which usually leaves the edge of the hole free.

Many failures by rupture are due to fusion, although some are caused by oxidation. The liability of the fabrics tested to failure by rupture was determined by subjecting the gauzes, assembled in single and in double gauze unbonneted lamps, to air mixtures moving horizontally at various velocities, proportioned at 6, 7, 8.6, and 11 per cent gas. The following table gives comparative results as determined by these tests:

Failure of gauze fabrics by rupture.

Gauze type.	Gas (per cent).	Occurrence of rupture.		
		Steel.	Brass.	Copper.
Double	11	No	At inner gauze and, in some tests, at outer gauze.	At inner gauze and, in some tests, at outer gauze.
Do	8.6	No	Both gauzes	Both gauzes.
Do	7	No	In some tests at inner gauze, but not at outer gauze.	In some tests at inner gauze, but not at outer gauze.
Do	6	No	No	No.
Single	11	No	Yes	In some tests.
Do	8.6	No	Yes	Do.
Do	7	No	No	No.
Do	6	No	No	No.

Reference to the results listed in the table above shows that steel gauzes did not rupture at any percentage of gas; and that brass and copper did not rupture at 6 per cent gas; brass always and copper usually ruptured at 8.6 per cent and at higher percentages. This variation in results is probably due to a combination of the following factors:

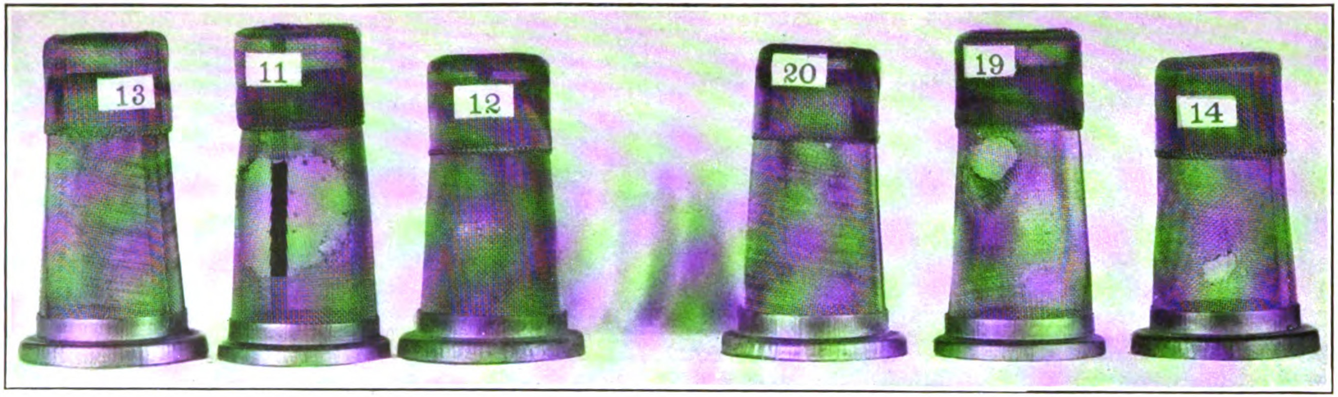
Change in the inflammability of the gaseous mixture.

Different rates of combustion within the gauze.

Specific conductivity, specific heat, and the degree of oxidation of the gauze material. (See discussion under "The proportion of gas present in the air current," p. 27.)

RELATIVE CONDUCTIVITY OF HEAT.

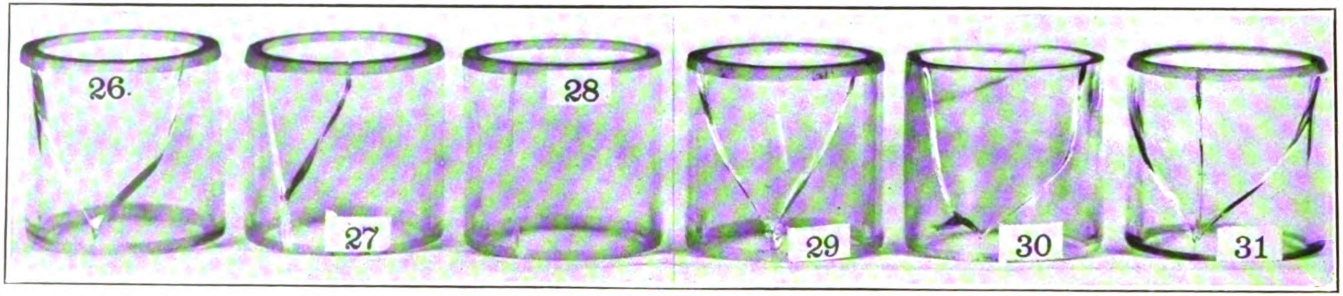
Heating of the parts of the lamp shows the effect of thermal conductivity. The lamp bowl and frame become hotter when the lamp has a copper gauze than when it has a brass or steel gauze, and a



Steel Brass Copper
Tests in 11 per cent gas.

Steel Brass Copper
Tests in 8.6 per cent gas.

A. GAUZES TESTED IN A CLANNY UNBONNETED LAMP, SHOWING APPEARANCE AFTER FAILURE.



B. LAMP GLASSES, SHOWING BREAKAGE CAUSED BY HOT GAUZES. GLASSES 27 AND 28 USED WITH BRASS GAUZES, OTHERS WITH COPPER GAUZES.

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lamp becomes appreciably hotter with a brass than with a steel gauze. This greater heating of the parts creates a condition that favors increased burning inside of the glass, and the flashes from the gauze to the glass, or internal explosions, become more frequent with copper gauze and less frequent with the steel gauze, as is shown by the cracking of the glass.

In certain tests failure by passage took place with steel gauzes when the gas was decreased. This result, which occurred with steel gauzes only, was probably due to the retention of the local high temperature of the gauze on account of the relatively lower conductivity of the steel. Slight variations in the test conditions had greater effect in changing the color of copper gauzes during the test than of other gauzes, owing to the good thermal conductivity of copper as compared with brass and steel. (See Pl. III, *A*.)

Conductivity has two opposing effects with respect to safety. A material having relatively good conductivity is desirable if the safety of gauze alone is to be considered, as such gauzes will remove heat from the flame, and by good distribution of the heat tend to keep both the gauze and the flame below a dangerous temperature. On the other hand, this rapid absorption of heat is transferred to other parts of the lamp, where it may cause trouble.

A few tests with brass and copper fabrics were made in both bonneted and unbonneted lamps having single gauze only. Tests were made at various velocities in 7, 8.6, and 11 per cent gas, and their duration was from 3 to 8 minutes. The chief object was to note the effect on the gauze and on lamp glass for each fabric.

Plate III, *B*, shows glasses that were cracked in these tests. The results appear in the following table:

Relative heating effect of different gauze fabrics.

Gauze material.	Type of lamp.	Gas.	Velocity of air mixture.	Duration of test.	Remarks.
		Per cent.	*Feet per minute.*	*Seconds.*	
Copper..	Clanny unbonneted.	11	600	516	Gauze bright red, slightly fused and ruptured; glass cracked.
Brass....	.....do...............	11	500	300	Gauze very bright red and coated with zinc oxide.
Copper...	.....do...............	7	1,000	318	Gauze very bright red; glass cracked badly.
Brass....	.....do...............	7	800	321	Gauze bright red; glass cracked in two places.
Copper...	Clanny bonneted....	8.6	2,000	314	Gauze dark red; fuel distillate burned in the glass about one-half of the time; glass cracked.
Do...	.....do...............	8.6	2,500	331	Gauze red; flashes of flame to glass; glass cracked.
Brass....	.....do...............	8.6	2,500	320	Gauze slightly oxidized; glass intact.
Do...	.....do...............	8.6	2,500	509	Bowl cool; glass cracked (1 vertical crack); gas burned steadily in gauze; fuel distillate burned around burner.
Copper...	.....do...............	8.6	2,500	503	Bowl hot; glass cracked (V-shaped break); gas burned steadily in gauze; fuel distillate burned around burner.
Steel....	.....do...............	8.6	2,500	502	Bowl cool; glass intact; no burning at burner.

The tests to determine the effect of thermal conductivity on safety, although too few to be conclusive, indicate that a material having a high degree of conductivity, such as copper, is unsuitable for gauze in a flame safety lamp, as heating may cause undue cracking of the lamp glasses and thus decrease the safety of the lamp. Brass, which has a much lower heat conductivity, gave more satisfactory results.

SPECIFIC HEAT.

This investigation has given no direct indication that the specific heat of the fabrics under test affected their protective qualities, but probably it had a considerable bearing on their relative behavior.

The specific heat of a material is the ratio of the heat required to raise a given volume of the material 1° to the heat required to raise an equal volume of water 1° from its temperature of maximum density. Therefore, if the metal of gauze *a* has twice the specific heat of gauze *b*, gauze *a* will absorb twice as much heat as gauze *b* in being heated to a given temperature. With a given amount of gas burning in the gauzes, it will take twice the time to heat gauze *a* and as safety depends upon the temperature of the gauzes, that gauze is safest whose metal has the highest specific heat.

The following table gives values of specific heats of iron, brass, and copper for the temperatures stated:

Specific heats of iron, copper, and brass at eight temperatures.[1]

	0° C.	50° C.	75° C.	100° C.	200° C.	300° C.	1,000° C.	1,400° C.
Iron	0.1116	0.1124	....	0.1138	0.1288	0.1267	....	0.4031
Copper	.0899	.0917	0.0932	.0942	.0963	.0985	0.1180	....
Brass	.0883	.0922	.0926	....	....	....	....	....

Corresponding values for the specific heat of low-carbon steel, such as was used in this investigation, are not available. The same authority, however, gave the specific heat of soft steel for temperatures 20°—98° C.=0.1165.

Reference to the table above shows that the specific heat varies with the temperature of the material, but that the rate for such variations in temperature is not the same for different materials. Between normal and melting point temperatures, the specific heat of copper increases about 31 per cent, whereas that of steel increases about 260 per cent. It will be noted also that the specific heat increases most rapidly as the temperature approaches the melting point of the given metal. The table shows that the specific heat of steel at any given temperature is always greater than that of copper, and, so far as specific heat is concerned, steel-gauze fabric is probably much safer than brass or copper gauze.

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[1] From Physico-Chemical tables, Chemical Engineering and Physical Chemistry, by J. Castell-Evans, vol. 1, pp. 183, 184.

EFFECT OF OXIDATION ON SAFETY.

Any consideration of the effect of oxidation on the safety of gauze fabric should include the entire temperature range through which the gauze may pass from normal atmospheric conditions with the lamp unlighted to the fusing temperature of the metals concerned, provided they fuse under conditions of possible service.

Oxidation, or the chemical uniting of the oxygen of the air with the metal of the gauze, may or may not be favorable to the safety of the gauze. If the oxide formed adheres to the wire and does not scale off readily, the diameter of the wire and the cooling effect of the gauze are increased, but the area of the gauze openings and the volume of air mixture admitted are decreased. With less gas burned, less heat is generated; and with more cooling material in the gauze there will be less probability that the gauze will become hot. Also, some of the oxygen that would normally be burned within the gauze enters into the oxidation process, thereby reducing the amount of heat generated. Finally, in case the wick flame is extinguished when gas enters the gauze but the air mixture within the gauze continues to burn, any inflammable vapor given off at the burner is less likely to ignite if there is a deficiency of oxygen. Although these conditions may favor safety, they do not favor good illumination, as any restriction of the air openings in the gauze would tend to make the burning of the lamp less efficient.

As regards conditions unfavorable to safety, oxidation of any kind ultimately lessens the mechanical strength of the gauze and renders it more liable in ordinary use to failure by cracks or by rupture. If oxides, instead of adhering, scale off easily, the diameter of the wires is not increased but is reduced, and the results are opposite to those enumerated above. Again, oxidation may seriously impair the mechanical strength of the gauzes, leaving them limp, shapeless, and easily ruptured.

TESTS TO DETERMINE PHYSICAL CHANGE.

Tests to determine physical changes and the relative oxidation of fabrics were made with single and double gauzes in both bonneted and unbonneted lamps. The procedure for these tests was as follows: Before test, the gauzes were weighed with an analytical balance. Then the tests were made by subjecting the lamp to various velocities and gas percentages for five minutes unless explosions were obtained in less time. After each test the gauzes were cleaned with a wire brush and reweighed to ascertain the change in weight. The results obtained are shown in Table 1.

TABLE 1.—*Change in weight of gauze fabrics through oxidation.*

Gauze material.	Type of lamp.	Test conditions.			Change in weight.			
		Gas.	Velocity of air mixture.	Duration of tests.	Loss.		Gain.	
		Per cent.	*Feet per minute.*	*Seconds.*	*Per cent.*		*Per cent.*	
Steel	Clanny unbonneted	11	1,000	71	0.07			
Copper	do	12.5	400	153	.47			
Steel	do	8.6	1,000	308	.24			
Brass	do	8.6	700	312	[1].07			
Do	Clanny bonneted	8.6	2,500	320			0.02	
Copper	do	8.6	1,500	311	1.8			
		8.6	2,000	314				
					Inner.	Outer.	Inner.	Outer.
Steel	Seippel unbonneted	8.6	1,200	303	0.81	0.10		
		8.6	1,500	13				
		8.6	1,200	22				
Brass	do	7	1,200	15			0.48	0.06
		7	1,000	302				
		7	800	120				
Do	do	6	1,200	21			.22	.07
		6	1,000	304				
		6	1,200	301				
		6	1,200	305				
Copper	do	6	1,500	304	1.6	.84		
		6	1,500	311				

[1] Gauze badly deteriorated.

It is seen by referring to Table 1 that steel and copper decreased in weight and brass increased in weight; the oxides, therefore, tend to adhere to the brass and to scale off steel and copper. The loss for copper is much greater than that for steel.

TESTS WITH NEW AND OXIDIZED GAUZES.

Tests were also made with new and oxidized gauzes, using the same gauze successively, in order to determine the effect of accumulative oxidation. The three materials—steel, brass, and copper—were tested in single and in double gauze bonneted lamps. The duration of each test was five minutes unless an explosion was obtained in less time. Tests were made with 6, 7, and 8.6 per cent gas.

The series of tests made with a single-gauze lamp are given in Table 2, and similar tests with double-gauze lamps are given in Table 3.

TABLE 2.—*Tests of single gauzes to determine effect of oxidation on safety.*

Gauze material.	Condition of gauze.[1]	Type of lamp.	Gas.	Velocity of air. mixture.	Duration of test.	Explosion.	Remarks.
			Per cent.	*Feet per minute.*	*Seconds.*		
Steel	New	Clanny unbonneted.	8.6	1,200	8	Yes[2]	Sharp single report; gauze not ruptured.
Do	Slightly oxidized	do	8.6	1,000	305	Yes	Explosion as gas was turned off; glass cracked.
Do	Slightly oxidized and cleaned.	do	8.6	1,000	308	Yes	Do.
Do	New	Davy	7	700	298	Yes	Explosion as gas was turned off; lamp burned at wick continually; flame lapped against side of gauze.
Do	Old and oxidized	do	7	700	307	No	Gauze bright red.
Brass	New	Clanny unbonneted.	8.6	800	92	Violent.	Gauze ruptured; white oxide deposit; glass cracked.
Do	Heavily oxidized	do	8.6	800	262	do	Gauze ruptured; white oxide deposit around burned out area.
Do	New	do	8.6	700	310	No	Gauze became bright red, bulged, oxidized, and became cooler.
Do	Oxidized	do	8.6	700	312	No	Gauze bright red.
Do	Cleaned	do	8.6	700	305	No	Gauze bright red; white oxide deposit; glass cracked.
Copper	New	do	7	1,000	6	Yes[2]	Gauze not ruptured.
Do	Heavily oxidized	do	7	1,000	318	No	Gauze very bright red; glass badly cracked.
Do	New	do	8.6	800	135	Yes[2]	Gauze not ruptured.
Do	Cleaned	do	8.6	800	301	No	Gauze fused and almost ruptured.

[1] "New" signifies no previous use; "cleaned;" previous use but loose oxide removed by wire brushing. Notes as to degree of oxidation refer to conditions of gauze from previous use.

[2] Failure by passage.

TABLE 3.—*Tests of double gauzes to determine effect of oxidation on safety.*

Gauze material.	Condition of gauze.[1]	Type of lamp.	Gas.	Velocity of air mixture.	Duration of test.	Explosion.	Remarks.
			Per cent.	*Feet per minute.*	*Seconds.*		
Steel	New	Seippel	6	1,200	17	Yes [2]	Gauzes not ruptured.
Do.	do.	do.	7	1,200	24	Yes [2]	Gauzes not ruptured; very slightly oxidized.
Do.	Oxidized	do.	7	1,200	22	Yes [2]	Gauzes not ruptured.
Do.	New	do.	8.6	1,200	309	No	Inner gauze oxidized.
Do.	Cleaned	do.	8.6	1,200	307	No	Inner gauze bright red; oxidized.
Do.	New	do.	8.6	1,500	14	Yes [2]	Violent explosion; gauzes not ruptured.
Do.	Slightly oxidized	do.	8.6	1,500	13	Yes [2]	Gauzes not ruptured.
Brass	do.	do.	6	1,200	301	No	Gauzes warped and inner gauze much deteriorated.
Do.	Oxidized	do.	6	1,200	305	No	Inner gauze bright red and touching outer gauze at downstream side.
Do.	New	do.	6	1,200	21	Yes [2]	Outer gauze distorted, but not ruptured.
Do.	Very slightly oxidized.	do.	7	1,000	314	No	Inner gauze bright red and almost burned through.
Do.	Oxidized	do.	7	1,000	302	No	Gauzes warped and inner gauze much deteriorated.
Copper	New	do.	6	1,500	304	No	Inner gauze became brittle; some pieces fell out in handling.
Do.	Oxidized	do.	6	1,500	311	No	Inner gauze ruptured; outer gauze red opposite hole in inner gauze.
Do.	Cleaned	do.	6	1,500	306	No	Outer gauze bright red; inner gauze almost ruptured.
Do.	New	do.	7	1,200	315	No	Inner gauze bright red.
Do.	Oxidized	do.	7	1,200	303	No	Inner gauze dull red.

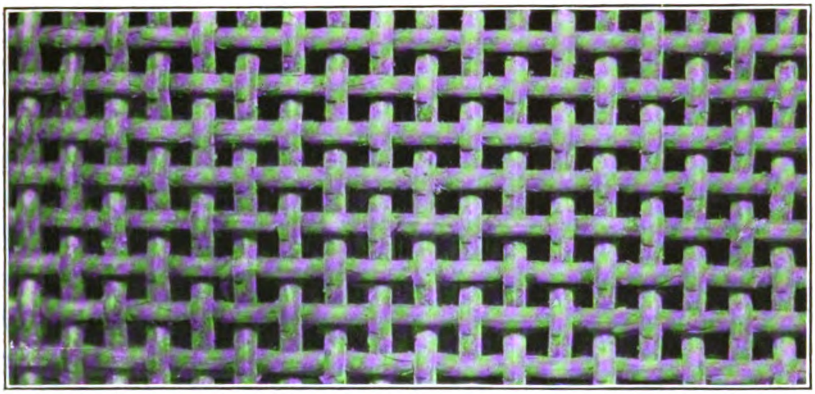
[1] See footnote on Table 2.

[2] Failure by passage.

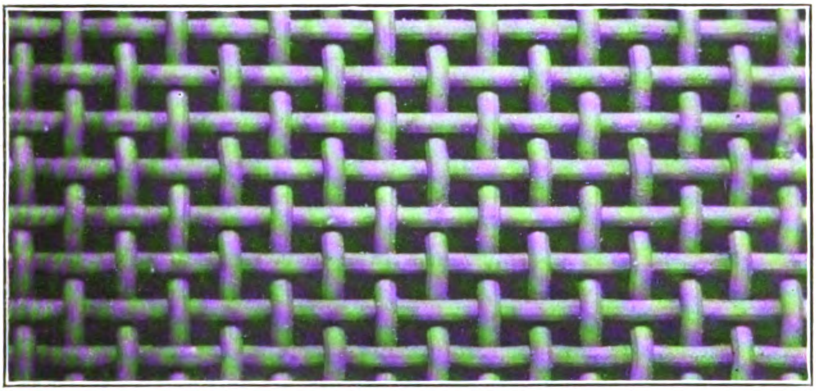
Reference to the groups of tests in Tables 2 and 3, where the variable is the condition of the gauze, shows that the general trend of safety is in favor of oxidized gauzes, for duration of the test before failure, percentage of gas causing failure, or velocity of the air mixture required to produce failure. Thus, although the evidence is not enough to be conclusive, it is evident that oxidation tended toward safety and in a certain sense increased the protective qualities of the gauzes.

TESTS OF SINGLE GAUZES IN BONNETED LAMPS.

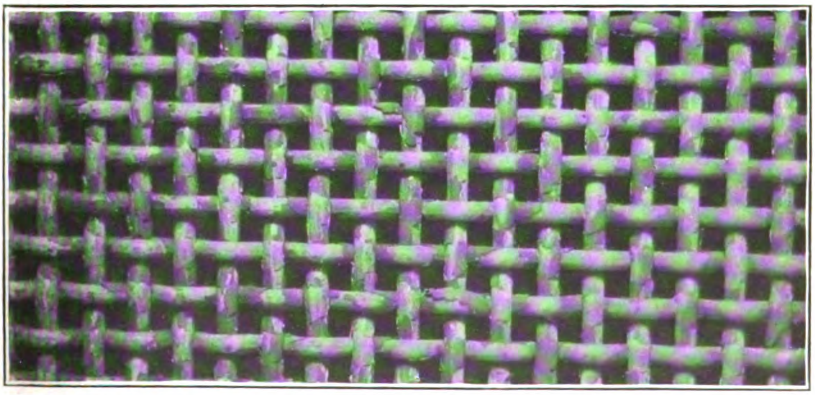
A single gauze of each fabric—steel, brass, and copper—was assembled in successive tests in a Clanny bonneted lamp. The tests were made in the testing gallery, with air mixture moving horizontally at 2,500 feet per minute. The gas percentage was 8.6 and the duration of each test about eight and one-third minutes. The object of these tests, particularly, was to study the effect of oxidation at lower temperatures than those prevailing with unbonneted lamps. The results of this series of tests were as follows: None of the tests resulted in explosions. The lamp bowls were cool when steel and



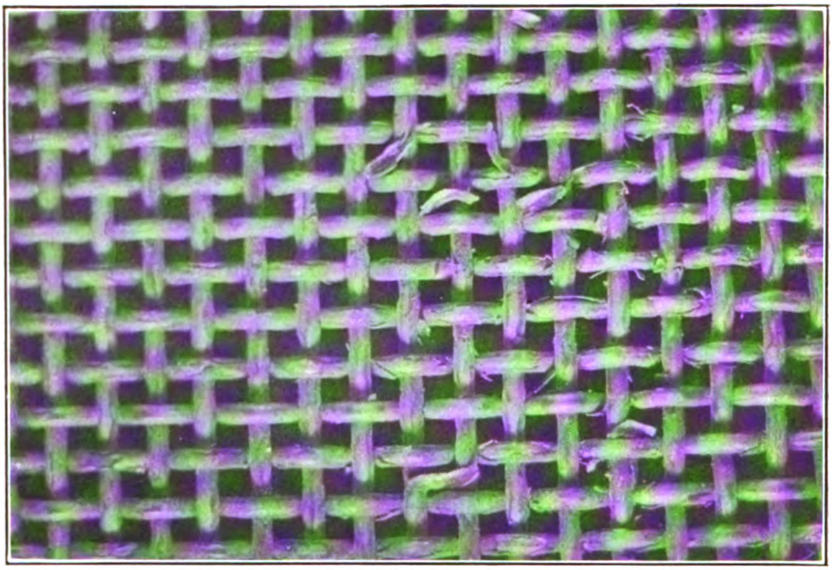
A. STEEL GAUZE, MAGNIFIED ABOUT 7 DIAMETERS, SHOWING OXIDATION AT DARK RED HEAT.



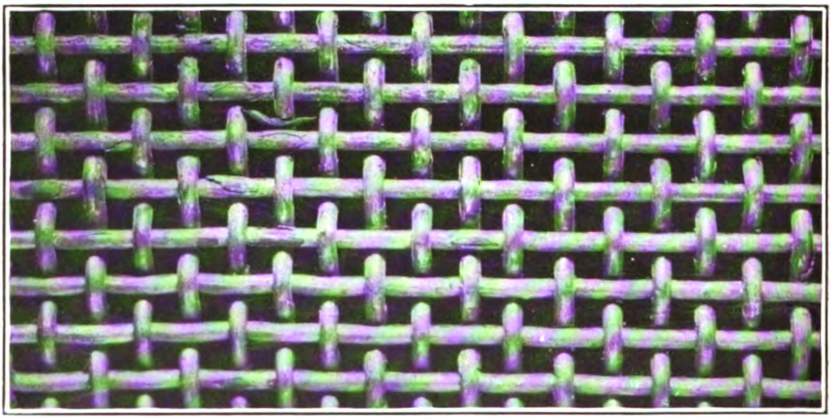
B. BRASS GAUZE, MAGNIFIED ABOUT 7 DIAMETERS, SHOWING NO APPRECIABLE OXIDATION AT DARK RED HEAT.



C. COPPER GAUZE, MAGNIFIED ABOUT 7 DIAMETERS, SHOWING OXIDATION AT DARK RED HEAT.



A. STEEL INNER GAUZE, MAGNIFIED ABOUT 7 DIAMETERS, SHOWING OXIDATION AT BRIGHT RED HEAT.



B. STEEL OUTER GAUZE, MAGNIFIED ABOUT 7 DIAMETERS, SHOWING OXIDATION AT BRIGHT RED HEAT.

brass gauzes were used, but not when a copper gauze was used; with all fabrics the flame burned in the gauze. With copper gauzes, the flame burned steadily around the burner, with brass it burned intermittently, and with steel it did not burn at all. In tests with brass and copper gauzes the glass was cracked; with steel it was intact.

Plate IV shows photomicrographs of the gauzes used in the above tests. Oxidation of the steel gauze is quite evident, many places on the wire showing spots where the oxide scaled off. This condition, however, would hardly be evident to the naked eye. The brass gauze shows practically no oxidation at this temperature; the copper gauze is in much worse condition than the steel gauze, and is oxidized to an extent that is quite evident to the naked eye.

The foregoing study is suggestive of the possible safe and economical use of brass if one can be assured that the temperature will never exceed that experienced in this test.

EFFECT OF OXIDATION ON SEVERAL FABRICS.

The action of oxidation, its effect on safety, and the behavior of the gauzes under the various conditions of the investigation are discussed for each fabric tested.

STEEL GAUZES.

At normal atmospheric temperature, steel oxidizes considerably. Gauze manufacturers recognize this fact and provide for it by giving the gauze an antirust coating that protects the gauzes until they are first put in service. After this coating is removed, oxidation undoubtedly takes place under all kinds of atmospheric conditions, but is probably much greater when the lamp is out of service than when burning. If the unused lamps are allowed to stay in damp rooms for a period of time the gauze is seriously oxidized.

Under conditions below bright red heat, no serious oxidation seemed to take place during the actual test and the condition of the gauze was excellent. For conditions above bright read heat, the test conditions did not subject steel gauzes to a temperature near the melting point of that material. Under the maximum conditions of the investigation, the steel gauzes retained their rigidity. The photomicrographs, Plate V, show some flaking of metal, but mechanically the safety of the gauze was in no sense impaired.

Steel-gauze fabrics undoubtedly undergo a process of slow, continuous oxidation that limits their safe life. The extent of the present investigation was not such as to show any serious deterioration. All failures obtained were due to subjecting the gauze in unbonneted lamps to moving air mixtures. Such failures were by “ passage ” and showed a lack of cooling action for the conditions prevailing, rather than any mechanical breakdown of the gauze material.

BRASS GAUZES.

Brass gauzes made of a quality of brass such as was used in the present investigation do not oxidize to any appreciable extent at normal atmospheric temperatures. At temperatures up to bright red heat, a smooth grayish-black oxide is formed that adheres tenaciously to the wires. Gauzes thus oxidized showed a slight increase in weight and probably under this condition were slightly safer than when new.

At bright red heat a fuzzy deposit of white zinc oxide is formed, as is shown very clearly in Plate VI. The temperature at which this oxide forms is very near the fusing point of the metal, and therefore it is difficult to determine just how far oxidation affects safety. In some of the tests, where failure occurred by rupture, a small hole appeared in the gauze. Many of the wires fringing the hole became oxidized and wasted away until only a visible thread of wire remained. At other points, actual fusion of the material was evident, and still farther from the hole were areas covered with zinc oxide. If the temperature of the gauze reached the melting point of brass, the gauze fused and failure occurred before much oxidation took place.

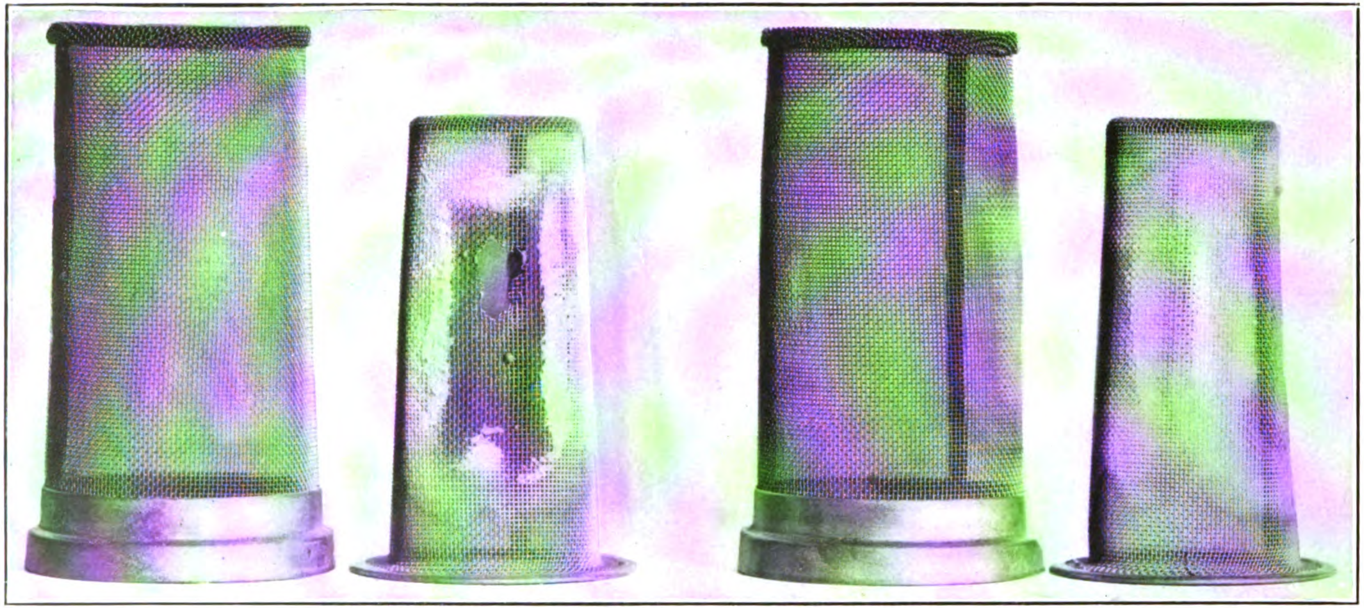
Plate VII shows an inner and outer brass gauze tested in a Seippel unbonneted lamp. These photomicrographs clearly show a deposit of fuzzy white zinc oxide. The wire of the outer gauze is not fused, and apparently the deposit came from the inner gauze, which deteriorated greatly.

COPPER GAUZES.

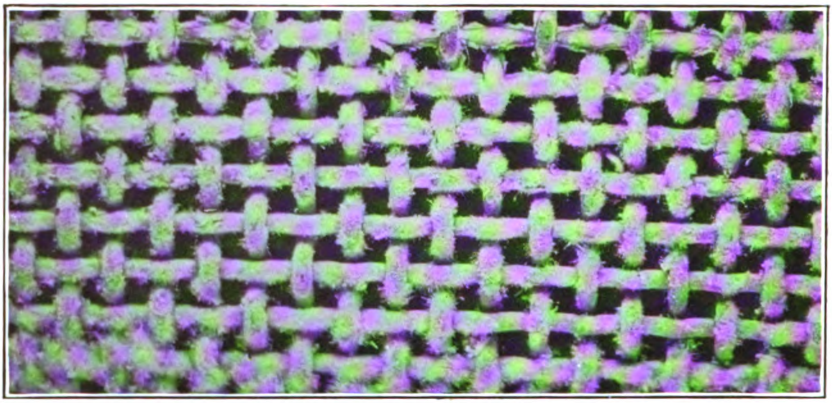
Copper guazes do not oxidize to any degree at normal atmospheric temperatures, but oxidize much at a temperature below a bright red heat.

At a dark red heat large flakes of copper oxide form (see Pl. IV, *C*), which scale off easily, leaving the wire smaller in diameter and in an annealed state. At near this temperature the gauzes, if handled, lose their rigidity, becoming limp and shapeless. At a bright red heat the oxidation is further increased and the wires become brittle (see Pl. VII, *C*) and break out when the gauze is given a jarring blow.

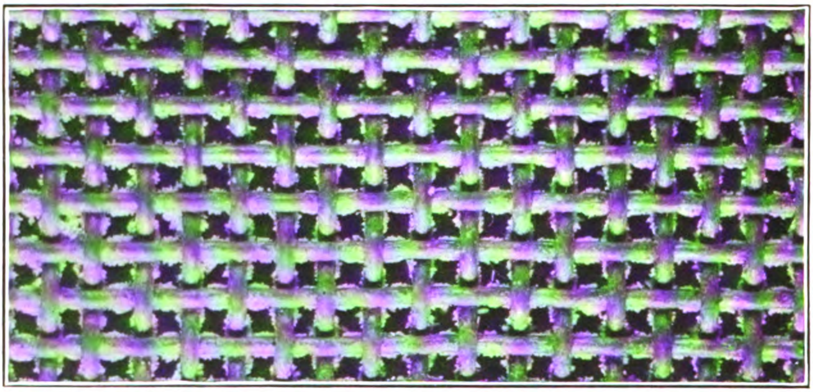
The tests made to determine relative oxidation showed copper to be inferior either to steel or brass. Under applied heat copper seriously oxidizes over a wide range of temperature. The condition of the material after such heating is mechanically unsafe, and its rigidity is unsatisfactory. Copper gauzes failed by both passage and rupture.



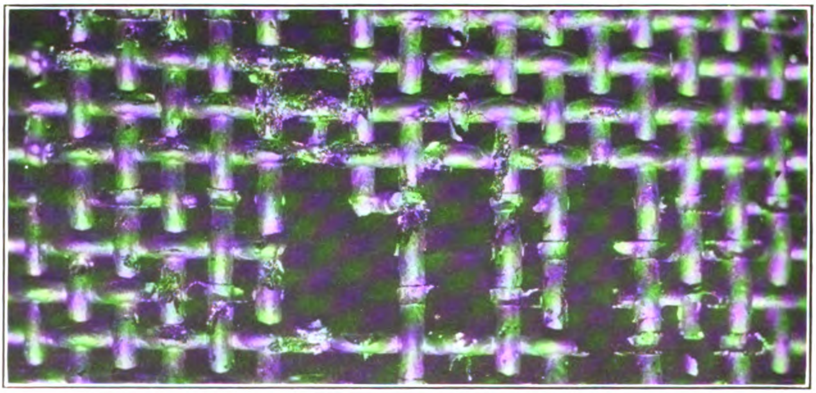
DOUBLE BRASS GAUZES, SHOWING COATING OF WHITE ZINC OXIDE.



A. BRASS INNER GAUZE, MAGNIFIED ABOUT 7 TIMES, SHOWING OXIDATION AT BRIGHT RED HEAT.



B. BRASS OUTER GAUZE, MAGNIFIED ABOUT 7 TIMES, SHOWING OXIDE COATING FROM THE INNER GAUZE.



C. COPPER INNER GAUZE, MAGNIFIED ABOUT 7 TIMES, SHOWING OXIDATION AT BRIGHT RED HEAT.

SUMMARY.

The following table shows the relative oxidation of different gauze fabrics under the conditions just outlined:

Comparative oxidation of gauze fabrics.

Condition of gauze.	Degree of oxidation.		
	Maximum.		Minimum.
Cold	Steel	[1]	[1]
Hot, below bright red heat	Copper	Steel	Brass.
Very hot, bright red heat and above	Brass	Copper	Steel.

[1] Brass and copper do not oxidize appreciably at ordinary atmospheric temperatures.

In conclusion it can be stated that for materials tested in the types of lamps used the results were as follows:

Steel did not oxidize seriously under the conditions of the present test. Brass oxidized very slightly in bonneted lamps. Copper heated above a dark red oxidizes in both bonneted and unbonneted lamps. For use in unbonneted lamps steel is much safer than either brass or copper. Brass proved much better than copper.

THE VELOCITY OF THE AIR MIXTURE.

Other variables remaining constant, safety with any gauze decreases with increase in velocity of the air mixture. Higher velocities cause more air mixture to enter the gauze and more heat to be developed within the gauze.

Tests made with lamps equipped with single gauzes indicated that brass and copper offer practically the same security against the passage of flame and that approximately 200 feet per minute greater velocity is required to produce a failure with a steel gauze. The velocities of air mixture selected were of such a range as to prove the maximum effectiveness of a given gauze. Hence most of the reported tests caused failures, but lower velocities would not generally have resulted in an explosion.

Tests made at various velocities are closely interlinked with tests made with various percentages of gas. Tables 4 and 5 show the results obtained when these two factors have varied. Table 4 gives comparative tests of steel, brass, and copper single gauzes when used in Clanny unbonneted lamp. Table 5 gives comparative tests of steel, brass, and copper double gauzes when used in a Seippel unbonneted lamp.

TABLE 4.—*Comparative tests of steel, brass, and copper single gauzes used in a Clanny unbonneted lamp, air mixture moving in horizontal direction.*

Gauze material.	Condition of gauze.[1]	Gas.	Velocity of air mixture.	Duration of test.	Explosion.	Remarks.
		Per cent.	*Feet per minute.*	*Seconds.*		
Steel.....	New..............	11	1,000	71	Yes [2]..	Gauze bright red.
Do...	Oxidized slightly..	8.6	1,000	305	Yes [3]..	Glass cracked.
Do...	New..............	8.6	1,200	8	Yes [3]..	Gauze ruptured.
Do...	Cleaned...........	8.6	1,000	308	Yes...	Gauze bright red; explosion as gas was turned off.
Do...	.....do............	7	1,200	11	Yes [3]..	
Do...	Oxidized slightly..	6	1,200	23	Yes [3]..	
Brass....	New..............	11	600	24	Yes [3]..	1 piece 1 inch square fell into lamp at wick holder.
Do...	.....do............	8.6	800	92	Yes [3]..	Gauze fused; white oxide deposit.
Do...	Oxidized..........	8.6	800	262	Yes [3]..	Deposit of white oxide.
Do...	Cleaned...........	8.6	700	305	No....	White oxide deposit; glass cracked.
Do...	New..............	7	1,000	6	Yes [2]..	No deposit of white oxide.
Do...	Cleaned...........	7	1,000	9	Yes [2]..	Gauze fused and almost ruptured.
Do...	Oxidized slightly..	6	1,000	14	Yes [2]..	No deposit of white oxide.
Do...	Cleaned...........	6	1,000	15	Yes [2]..	Do.
Do...	New..............	6	1,000	10	Yes [2]..	Do.
Copper...	Oxidized..........	11	600	48	Yes [3]..	
Do...	.....do............	8.6	1,000	9	Yes [3]..	
Do...	Cleaned...........	8.6	1,000	6	Yes [3]..	
Do...	New..............	8.6	600	135	Yes [2]..	
Do...	Cleaned...........	8.6	800	301	No....	Gauze fused and almost ruptured.
Do...	.....do............	8.6	800	21	Yes [3]..	
Do...	New..............	7	1,000	6	Yes [2]..	
Do...	Oxidized slightly..	6	1,000	14	Yes [2]..	

[1] See footnote on Table 2.

[2] Failure by passage.

[3] Failure by rupture.

TABLE 5.—*Comparative tests of steel, brass, and copper double gauzes used in a Seippel unbonneted lamp, air mixture moving in horizontal direction.*

Gauze material.	Condition of gauze.[1]	Gas.	Velocity of air mixture.	Duration of test.	Explosion.	Remarks.
		Per cent.	*Feet per minute.*	*Seconds.*		
Steel.....	New..............	11	1,500	9	Yes [2]..	
Do...	.....do............	8.6	1,500	14	Yes [2]..	
Do...	Cleaned...........	8.6	1,500	13	Yes [2]..	
Do...	.....do............	8.6	1,200	303	No....	Inner gauze bright red.
Do...	New..............	7	1,200	24	Yes [2]..	
Do...	Cleaned...........	7	1,200	22	Yes [2]..	
Do...	Slightly oxidized..	7	1,500	12	Yes [2]..	
Do...	New..............	6	1,200	17	Yes [2]..	
Do...	.....do............	6	1,500	11	Yes [2]..	
Brass....	.....do............	11	700	25	Yes [2]..	Inner gauze ruptured in 20 seconds; outer gauze not ruptured.
Do...	.....do............	8.6	1,000	57	Yes [3]..	Gauzes fused and blown to pieces. (See fig. 17, Pl. III, *A*.)
Do...	Slightly oxidized..	8.6	1,000	175	Yes [3]..	Both gauzes ruptured, inner one badly.
Do...	New..............	7	1,200	15	Yes [2]..	Inner gauze distorted, not ruptured; no deposit of white oxide.
Do...	Cleaned...........	7	1,000	302	No....	Outer gauze warped and inner gauze much deteriorated.
Do...	New..............	6	1,200	21	Yes [2]..	Outer gauze distorted, not ruptured; no deposit of white oxide.
Do...	Cleaned...........	6	1,000	304	No....	Inner gauze bright red.
Do...	Oxidized..........	6	1,200	301	No....	Inner gauze warped and deteriorated.
Copper...	New..............	11	1,000	163	Yes [3]..	Inner gauze ruptured in 6 seconds; small hole in outer gauze.
Do...	.....do............	8.6	1,200	18	Yes [3]..	Both gauzes ruptured.
Do...	Oxidized..........	7	1,500	16	Yes [3]..	Inner gauze ruptured in 12 seconds; outer gauze oxidized.
Do...	New..............	6	1,500	304	No....	Inner gauze became brittle; a few small holes resulted.
Do...	Cleaned...........	6	1,500	306	Yes...	Inner gauze almost ruptured.
Do...	Heavily oxidized..	6	2,000	6	Yes [3]..	Outer gauze oxidized; several small holes in inner gauze.

[1] See footnote on Table 2.

[2] Failure by passage.

[3] Failure by rupture.

PROPORTION OF GAS IN THE AIR MIXTURE.

The composition of Pittsburgh natural gas,[4] which was used in this investigation, is approximately 82 per cent methane, 16.4 per cent ethane, and 1.5 per cent nitrogen. The physical characteristics of this gas resembled those of its chief constituent, methane. Its explosive limits when mixed with air [5] are approximately 5 to 12 per cent. The point of greatest explosibility is about 8.6 per cent.[6]

The relative proportion of methane and ethane in the gas varied somewhat during the tests, which extended over a period of several months, but it is believed that the test results were not materially affected by the variations.

In studying the relative safety of the three fabrics under investigation, an endeavor was made to determine whether the protective features of each fabric were influenced by a change in the percentage of gas in the gas-air mixture. Tests were made at four different points within the explosive limits of the gas, namely, at 6, 7, 8.6, and 11 per cent. Further details respecting procedure are given under the descriptions below of the tests with a given type of lamp. Three types of lamps were used in studying the effect of changing the percentage of the gas.

TESTS WITH A DAVY LAMP.

Tests were made with a common Davy lamp at 6, 7, and 8.6 gas percentages. The lamp, equipped with a single steel gauze, was suspended in the testing gallery and subjected to air-gas mixtures moving horizontally. The velocity of the mixture was varied for each percentage of gas.

Six per cent gas mixtures gave explosions at 800 feet velocity, but 7 and 8.6 per cent gas mixtures did not. If, however, the proportion of gas in the 7 and 8.6 per cent mixtures was slightly decreased by slowly closing the gas valve, the velocity being held constant at 800 feet per minute, explosions resulted. Also, an explosion could be obtained in the same manner by decreasing the gas of a 6 per cent mixture while the velocity was kept at 700 feet per minute. A single steel gauze in a Davy lamp is least safe, therefore, near the lower explosive limit of the gas; that is, between 5.5 and 6 per cent.

Brass and copper gauzes were not available for tests with the Davy lamp.

TESTS WITH A CLANNY LAMP.

In tests with a single-gauze unbonneted lamp of the Clanny type, the lamp was equipped in turn with each of the fabrics under investigation. Tests were made in the testing gallery, the lamp being subjected to air-gas mixtures moving horizontally and containing 6, 7, 8.6, and 11 per cent gas. The velocity range of the mixture was 700 to 1,200 feet per minute.

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[4] Hall, Clarence, Snelling, W. O., and others, Investigations of explosives used in mines: Bull. 15, Bureau of Mines, 1912, p. 66.

[5] Work cited, p. 71.

[6] Work cited, p. 74.

Varying the percentage of gas did not appreciably affect the protective limits of brass and copper gauzes, but it indicated that a high percentage was more liable to cause the failure of a steel gauze, as an 11 per cent mixture gave failures at a velocity of 1,000 feet per minute, whereas a velocity of 1,200 feet per minute was required for lower percentages of gas. In this type of lamp, steel gauzes proved safer at all percentages of gas than brass or copper, which gave explosions with an 11 per cent mixture at 600 feet per minute and with a 6 per cent mixture at 1,000 feet per minute.

TESTS WITH A SEIPPEL LAMP.

In tests with a double-gauze unbonneted lamp of the Seippel type, each material under investigation was assembled in turn in the lamp and tested in the testing gallery in horizontally moving mixtures. Tests were made at the four percentages of gas already mentioned and at various velocities of air mixture.

Steel gauzes increased in safety with an increased percentage of gas; with 6 per cent gas, explosions were obtained at a velocity of 1,200 feet per minute, whereas with 11 per cent gas a velocity of 1,500 feet per minute was needed to cause a passage. Brass gauzes decreased in safety with increased percentages of gas, with a 6 per cent mixture a velocity of 1,200 feet per minute was required to cause an explosion, whereas an 11 per cent mixture caused failure with a velocity of only 700 feet per minute. Copper also decreased in safety with an increased percentage of gas; with 6 per cent gas a velocity of 1,500 to 2,000 feet per minute was required to cause an explosion, whereas with 11 per cent gas a velocity of 1,000 feet per minute was enough.

BRIEF DISCUSSION OF RESULTS OF THE TESTS.

An attempt to explain why one fabric is safer at a low percentage of gas and another is safer at a high percentage, or why the same material gives different relative results when tested in a different type of lamp, leads into a labyrinth of discussion and speculation.

The factors involved are many and their individual effects are difficult to determine; any theories that might be evolved, therefore, would be open to question. The most satisfactory manner of handling the question of variations in results with different proportions of gas is to give the actual results obtained and to point out some of the factors that probably have influenced these results, rather than to go into lengthy discussions of what can not be proved by the data at hand.

The factors that singly, or in combination, are believed to have caused the variation in the results obtained in tests made with the fabrics at the various gas percentages are as follows:

1. The specific heat of the gauze material. Some materials retain a dangerous temperature for a longer time while the gas percentage is being varied.

2. The degree of oxidation of the gauze is believed to be influenced by the percentage of gas present, and this in turn may influence the rate of combustion due to catalysis and surface effects. The oxide coating changes the fusibility of the gauze wire, so more heat and in many cases a higher temperature are required to rupture a gauze.

3. The conductivity of the gauze materials. Conductivity is believed to have a varying influence at different percentages of gas.

4. The velocity of the air mixture. The effect on the other variables is probably not in direct proportion.

5. The number of gauzes. The effect of the variables already mentioned are believed to be different for a single gauze than for a double gauze.

6. The glass around the burner. The glass, which is used in all lamps tested except the Davy, causes entirely different conditions of burning at the wick, protects the wick flame from direct contact with the gauze, and produces a decidedly different effect in the general behavior of the lamp.

CONSTRUCTION OF THE LAMP.

The factors that enter into the design, construction, and operation of flame lamps and influence the effectiveness of the protective qualities of a given gauze material are as follows:

1. Bonneted versus unbonneted lamps.
2. Top feed versus bottom feed.
3. Oil versus naphtha as a fuel.
4. Method of relighting lamp.
5. Use of lamp standards in unbonneted lamps.
6. Means used for security or assembly of the gauze.

Each of the above factors might well be made the subject of an investigation. In the present investigation, although all of the factors mentioned entered in as variables, the observations were not complete enough for drawing final conclusions.

The relative protection afforded by bonneted and unbonneted lamps seems fairly well established.

There was a marked increase in safety when using lamps of the bonneted type, whether single or double gauze. This result is easily explained. The bonnet not only shields the lamp from the direct air current and prevents the flame from being blown against the gauze but also diminishes the amount of air mixture that enters the lamp during a given time. A decrease in the amount of air mixture means a corresponding decrease in the amount of gas burned, and a consequent decrease in the heat to be dissipated.

Certain tests and data selected from the investigation bearing on the relative safety of bonneted and unbonneted lamps are given in the illustrations and tables that follow.

Plates II and III, *B*, show the appearance of gauzes tested in unbonneted lamps. These gauzes all caused failures.

Relative safety of bonneted and unbonneted lamps.

Type of lamp.	Type of gauze.	Gauze material.	Velocity of air mixture.	Gas.	Failure.
Bonneted:			*Feet per minute.*	*Per cent.*	
Clanny	Single	Steel	2,500	8.6	No.
Do	...do	Brass	2,500	8.6	No.
Do	...do	Copper	2,500	8.6	No.
Koehler	Double	Steel	2,500	8.6	No.
Do	...do	Brass	2,500	8.6	No.
Do	...do	Copper	2,500	8.6	No.
Unbonneted:					
Clanny	Single	Steel	1,200	[1] 6	Yes.
Do	...do	Brass	800	8.6	Yes.
Do	...do	Copper	800	8.6	Yes.
Seippel	Double	Steel	1,500	[2] 6	Yes.
Do	...do	Brass	1,000	8.6	Yes.
Do	...do	Copper	1,200	8.6	Yes.

[1] Failures also obtained, at the velocity stated, with 7 per cent gas.
[2] Failures also obtained, at the velocity stated, with 11 per cent gas.

COMPARISON OF TESTS WITH THOSE MADE BY BELGIAN INVESTIGATORS.[7]

One purpose of this investigation was to check work done by European investigators. The series of tests made by Watteyne and Stassart were found particularly applicable, as several kinds of gauze material were investigated as well as several types of mine lamps.

Although many things were in common in the two investigations, several differences should be mentioned. The Belgian tests were made primarily to study the relative safety of oil and naphtha as fuels for various types of lamps, and the study of gauze materials was secondary to the main investigation, whereas the main object of the present investigation was to study the relative safety of different gauze materials, other conditions being secondary. The Belgian investigation covered many more tests and were made with air mixtures moving vertically and at an angle as well as horizontally. The gauze materials used in those tests were iron, brass (75 per cent Cu, 25 per cent Zn), and copper; whereas steel, brass (80 per cent Cu, 20 per cent Zn), and copper were used in this investigation. The lamps of the unbonneted type were about the same for each investigation; the lamps of the bonneted type differed in several respects. The following types of bonneted lamps were used by the Belgian investigators:

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[7] Watteyne, V., and Stassart, S., [Experiments on safety lamps]: **Ann. mines de Belgique**, t. 9, 1904, pp. 947–1251.

Marsaut, a single-gauze, bonneted, middle-feed lamp.

Mueseler, a single-gauze, bonneted, middle-feed lamp having a combustion tube within the gauze.

Marsaut, a double-gauze, bonneted, middle-feed lamp.

Wolf, a double-gauze, bonneted, middle-feed lamp.

The following types of bonneted lamps were used in this investigation.

Clanny, a single-gauze, bonneted, middle-feed lamp.

Koehler, a double-gauze, bonneted, bottom-feed lamp.

The brass used in the Belgian investigation contained less copper than the brass used in the present investigation.

Comparison of results of tests at Pittsburgh, Pa., and at Framerics, Belgium.

Belgian investigation.

Number of gauzes.	Gauze material.	Unbonneted lamps.				Bonneted lamps.			
		Type of lamp.	Velocity.	Methane.	Failure.	Type of lamp.	Velocity.	Methane.	Failure.
			Feet per minute.	*Per cent.*			*Feet per minute.*	*Per cent.*	
Single	Iron	Large type lamp.	800	8	Yes		[1] 1,000	9	No.
Do	Brass	do	600	8	Yes				
Do	Copper	do	600	8	Yes				
Double	Iron	Lampe de porion.	1,400-1,800	8	Yes	Wolf (top feed) and Marsaut.	3,000	8	No.
Do	Brass	do	1,200	8	Yes	do	3,000	8	No.
Do	Copper	do	1,400	8	Yes	do	3,000	8	No.

[1] This was the maximum velocity used in tests of single-gauze bonneted lamps.

Bureau of Mines investigation.

Number of gauzes.	Gauze material.	Unbonneted lamps.				Bonneted lamps.			
		Type of lamp.	Velocity.	Gas.	Failure.	Type of lamp.	Velocity.	Gas.	Failure.
			Feet per minute.	*Per cent.*			*Feet per minute.*	*Per cent.*	
Single	Steel	Clanny	1,200	8.6	Yes	Clanny	2,500	8.6	No.
Do	Brass	do	800	8.6	Yes	do	2,500	8.6	No.
Do	Copper	do	800-1,000	8.6	Yes	do	2,500	8.6	No.
Double	Steel	Seippel	1,200	8.6	Yes	Koehler	2,500	8.6	No.
Do	Brass	do	1,000	8.6	Yes	do	2,500	8.6	No.
Do	Copper	do	1,200	8.6	Yes	do	2,500	8.6	No.

The Belgian results indicated that single-gauze unbonneted lamps were least safe, that double-gauze unbonneted lamps were considerably more safe, and that bonneted lamps of all types did not give explosions; also that at high temperatures, with 8 per cent methane, the order of safety of the several fabrics investigated was (1) iron, (2) copper, and (3) brass.

The Bureau of Mines investigation indicated the same results with respect to the safety of the different types of lamps, but that the order of safety for the materials tested was (1) steel, (2) brass, and (3) copper. The more favorable results obtained with brass in the Bureau of Mines tests are probably due to the quality of the brass, which had a much higher melting temperature than that used by the Belgian investigators.

CONCLUSIONS.

The behavior of the different gauze fabrics has in a general way checked the results obtained by Belgian investigators. When the differences in the materials tested, together with possible differences in the test conditions, are considered, it is remarkable that the results in many tests follow so closely the conclusions of investigators abroad.

For conditions of high temperature, steel proved superior to either brass or copper. For low temperatures, the advantage of steel over brass or copper is little. Brass or copper might be preferred by some, although one who knows the insecurity of such gauzes at high temperature might be unwilling to trust them, even though the probability of high temperatures was remote.

Brass proved more satisfactory than copper, but the brass gauzes tested had a high proportion of copper and therefore may have given much better results than would have been obtained with some other brass.

In conducting the tests of the gauze fabrics under various possible conditions of service certain points were brought out forcibly. The least safe of all the lamps tested is the single-gauze unbonneted lamp of the Davy type. In fact, compared with a bonneted lamp of modern design it should not be classified as a safety lamp. The condemnation of the Davy lamp as a safety device for present-day conditions does not belittle the great work done by Davy, for almost every modern lamp uses principles he advocated.

The double-gauze unbonneted lamp is somewhat safer than a single-gauze lamp, but is not dependable in high-velocity air mixtures.

The single-gauze bonneted lamp proved safer than either type of unbonneted lamp; the omission of a gauze is more than offset by the bonnet.

The safest lamp tested was the double-gauze bonneted lamp, which has the protective features of the single-gauze bonneted lamp and the added safety of another gauze in case either gauze of a pair should become damaged. In this investigation the Hailwood combustion-tube lamp was not tested, but previous tests by the bureau have shown it to be as safe as a double-gauze bonneted lamp of the Koehler type.

The chief object of the investigation was to determine whether the gauze specifications of Schedule 7 needed revision. The results indicate that present specifications, though perhaps not detailed enough, rest on a sound foundation, and that a lamp meeting these requirements would have a high standard of safety. It may later be deemed best to permit the use of brass gauze in bonneted lamps, but until the subject is investigated further the schedule should not be changed in that respect. A requirement that only bonneted lamps be admitted as permissible for use in gaseous mines could well be added as a step toward greater safety.

The possibility of using monel metal or nickel for flame-lamp gauze has been suggested, as these materials have a higher melting point than steel, have about the same heat conductivity, and resist oxidation at atmospheric and at high temperatures. These materials should be investigated.

PUBLICATIONS ON COAL MINING.

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PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 1911. 61 pp., 10 pls., 12 figs.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 1911. 204 pp., 14 pls., 28 figs.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 29 figs.

BULLETIN 45. Sand available for filling mine workings in the northern anthracite coal basin of Pennsylvania, by N. H. Darton. 1912. 33 pp., 8 pls., 5 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1914. 50 pp., 3 pls., 7 figs.

BULLETIN 50. A laboratory study of the inflammability of coal dust, by J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, jr. 1913. 60 pp., 95 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 57. Safety and efficiency in mine tunneling, by D. W. Brunton and J. A. Davis. 1914. 271 pp., 6 pls., 45 figs.

BULLETIN 60. Hydraulic mine filling, its use in the Pennsylvania anthracite fields, a preliminary report, by Charles Enzian. 1913. 77 pp., 3 pls., 12 figs.

BULLETIN 68. Electric switches for use in gaseous mines, by H. H. Clark and R. W. Crocker. 1913. 40 pp., 6 pls.

Bulletin 74. Gasoline mine locomotives in relation to safety and health, by O. P. Hood and R. H. Kudlich, with a chapter on methods of analyzing exhaust gases, by G. A. Burrell. 1916. 84 pp., 3 pls., 27 figs.

Bulletin 78. Approved explosion-proof coal-cutting equipment, by L. C. Ilsley and F. J. Gleim. 53 pp., 18 pl., 3 figs.

Bulletin 90. Abstracts of current decisions on mines and mining, December, 1913, to September, 1914, by J. W. Thompson. 1915. 176 pp.

Bulletin 93. Miners' nystagmus, by F. L. Hoffman. 1916. 67 pp.

Bulletin 99. Mine-ventilation stoppings, with especial reference to coal mines in Illinois, by R. Y. Williams. 1915. 30 pp., 4 pls., 4 figs.

Bulletin 101. Abstracts of current decisions on mines and mining, October, 1914, to April, 1915, by J. W. Thompson. 1915. 138 pp.

Bulletin 102. The inflammability of Illinois coal dusts, by J. K. Clement and L. A. Scholl, jr. 1916. 74 pp., 5 pls., 22 figs.

Bulletin 105. Black damp in mines, by G. A. Burrell, I. W. Robertson, and G. G. Oberfell. 1916. 92 pp.

Bulletin 118. Abstracts of current decisions on mines and mining, reported from October to December, 1915, by J. W. Thompson. 1916. 74 pp.

Bulletin 126. Abstracts of current decisions on mines and mining, reported from January to April, 1916, by J. W. Thompson. 1916. 90 pp.

Bulletin 131. Approved electric lamps for miners, by H. H. Clark. 1917. 59 pp., 17 pls., 7 figs.

Bulletin 137. The use of permissible explosives in the coal mines of Illinois, by J. R. Flemming and J. W. Koster. 1917. 110 pp., 8 pls., 17 figs.

Bulletin 172. Abstracts of current decisions on mines and mining, reported from January to April, 1918, by J. W. Thompson. 1918. 160 pp.

Bulletin 174. Abstracts of current decisions on mines and mining, reported from May to September, 1918, by J. W. Thompson. 1919. 138 pp.

Bulletin 175. Experiment stations of the Bureau of Mines, by Van H. Manning. 1919. 106 pp., 29 pls., 2 figs.

Bulletin 181. Abstracts of current decisions on mines and mining, reported from January to May, 1919, by J. W. Thompson. 1919. 176 pp. 15 cents.

Bulletin 183. Abstracts of current decisions on mines and mining, reported May to August, 1919, by J. W. Thompson. 1920. 167 pp.

Bulletin 196. Coal-mine fatalities in the United States, 1919, and coal-mine statistics supplementing those published in Bulletin 115, with list of permissible explosives, lamps, and motor tests prior to January 31, 1920, by A. H. Fay. 1920. 86 pp.

Technical Paper 2. The escape of gas from coal, by H. C. Porter and F. K. Ovitz. 1911. 14 pp., 1 fig.

Technical Paper 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.

Technical Paper 21. The prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 1912. 12 pp.

Technical Paper 43. The effect of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

Technical Paper 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.

Technical Paper 62. Relative effects of carbon monoxide on small animals, by G. A. Burrell, F. M. Seibert, and I. W. Robertson. 1914. 23 pp.

Technical Paper 75. Permissible electric lamps for miners, by H. H. Clark. 1914. 21 pp., 3 figs.

TECHNICAL PAPER 82. Oxygen mine-rescue apparatus and physiological effects on users, by Yandell Henderson and J. W. Paul. 1917. 102 pp., 5 pls., 6 figs.

TECHNICAL PAPER 84. Methods of preventing and limiting explosions in coal mines, by G. S. Rice and L. M. Jones. 1915. 50 pp., 14 pls., 5 figs.

TECHNICAL PAPER 103. Organizing and conducting safety work in mines, by H. M. Wilson and J. R. Fleming. 1917. 57 pp., 35 figs.

TECHNICAL PAPER 108. Shot firing in coal mines by electricity controlled from the outside, by H. H. Clark, N. V. Breth, and C. M. Means. 1915. 36 pp.

TECHNICAL PAPER 112. The explosibility of acetylene, by G. A. Burrell and G. G. Oberfell. 1915. 15 pp.

TECHNICAL PAPER 121. Effects of temperature and pressure on the explosibility of methane-air mixtures, by G. A. Burrell and I. W. Robertson. 1916. 14 pp., 3 figs.

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